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THE FIRST EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS-1)

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ABSTRACT

The first Earth Resources Technology Satellite (ERTS-1) makes images of the earth's surface in four portions of the electromagnetic spectrum with sufficient spatial resolution and with a minimum of geometric distortions, so that these images may be applied experimentally to the study of geophysical processes relating to earth resources, to the exploration and conservation of these resources and to the assessments of environmental stresses. During the first six months of operation, ERTS-1 has imaged 6.5 million square kilometers of the earth's surface every day, covering most major land masses and costal zones as well as both polar regions of this planet.

These images as well as the results of their analyses are available to all people throughout the world. Scientific investigators of all countries have been invited to participate in the utilization of ERTS-1 observations. Many of them have already demonstrated the great efficiency, economy, and reliability of making earth surveys from space.

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CONTENTS

THE FIRST EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS-1)

THE ERTS-1 SYSTEM

The ERTS-1 system consists of a spacecraft and a very complex ground facility, which, to a large extent, outweighs the spacecraft in complexity and significance. The spacecraft is an outgrowth of and very similar to the Nimbus meteorological satellites. Many of the subsystems on the spacecraft are the same as those on Nimbus. An outline drawing of the ERTS-1 spacecraft and its payload is shown in Figure 1. ERTS-1 differs from NIMBUS mainly in the sensors which are carried by the spacecraft. They are: three Return Beam Vidicon (RBV) television cameras, and a Multi-Spectral Scanner (MSS). These two sensors are designed to measure sunlight reflected by the earth in four spectral bands; namely, in the green and yellow/red portions of the visible spectrum and in the infrared at a wavelength near 0.8 micrometers. The MSS alone, is sensitive to a fourth band in the infrared, near a wavelength of 1.0 micrometer.

ERTS-1 also carries a Data Collection System which acquires transmissions from ground platforms distributed over North America. The satellite retransmits the messages from these platforms to a central facility at the Goddard Space Flight Center. These messages consist of measurements such as water quality, rainfall, snow depth, and seismic activity. The measurements are made by the platforms directly and automatically at remote and inaccessible sites.

During daytime, the satellite passes from 80°N to 80°S in a south-southwesterly direction and transmits the optical measurements made by the Return Beam Vidicon cameras and the Multi-Spectral Scanner directly to receiving stations located at the Goddard Space Flight Center; Goldstone, California; Fairbanks, Alaska; and to a Canadian Station in Saskatchewan. The government of Brazil has constructed a fifth station, which is expected to be fully operational during late 1973. During nighttime, the satellite transmits the measurements recorded over other parts of the world to the three U.S. stations only.

All satellite passes occur at approximately the same local time at each location; namely, between 9:00 and 10:00 in the morning every day. The fields of view of the two sensor systems are identical and cover a strip 185 kilometers (100 nautical miles) wide directly underneath the spacecraft. Images are taken along selected portions of these orbital strips. At the equator, the centers of successive strips are spaced 2800 kilometers apart, so that 14 such strips may be observed around the world every day. The orbit is adjusted so that a strip observed on one given day, in one given location, advances westward by about 170 kilometers on the next day. In this fashion, as each strip advances from day to day contiguously, the entire world between 80°N and 80°S is viewed by these ERTS sensors once every 18 days. However, limited power, data transmission and, above all, data processing capacity, prevent acquisition of images over the entire world during every 18-day period. Thus, contiguous images are acquired every 18 days only over the North American continent. For the rest of the world, selected strips over portions of the orbit track are imaged. Every day, these strips amount to about 26,000 kilometers in length and 185 kilometers in width. They are chosen on the basis of cloud cover forecasts and on the basis of investigators who have expressed interest in ERTS-1 coverage of such areas and have reached agreements with NASA in advance.

Every day about 10^{10} digital bits are transmitted electronically and are converted to about 1350 photographic images at the NASA Data Processing Facility at Goddard Space Flight Center. Approximately ten copies of each of these images are made and distributed to several U.S. Government agencies: the U.S. Army Corps of Engineers, the Department of Commerce, the Department of Interior, and the Department of Agriculture. Both the Department of Commerce and the Department of Interior archive all the photographs which they receive at their data centers, and ERTS-1 photographs may then be purchased from these data centers by the general public. In addition, NASA has reached agreements for analysis of ERTS images with about 320 investigators, of whom about 100 are from 36 countries outside the United States. These investigators attempt to apply the ERTS-1 observations of landforms and land use patterns to the assessment of mineral, agricultural and other land resources; the observations of snow, ice, lakes, and rivers to the assessment and prediction of water supply and quality and to the analyses of floods; and the observations of oceans and estuaries to the assessment of ocean food resources, sedimentation and erosion processes and the quality of the coastal environment.

STATUS OF ERTS-1

ERTS-1 was launched on 23 July 1972. Picture taking was activated two days later. The spacecraft, its sensors and associated picture generation and distribution systems have been in operation since then. As of the end of June 1973, the system was still operational. ERTS-1 has met its primary and secondary objectives which were: to demonstrate the utility of multi-spectral images, acquired periodically over North America, to the survey and management of earth resources and the detection of environment stresses; and to acquire multi-spectral images of major land masses on a global scale, respectively. All design goals of the ERTS-1 system have also been largely fulfilled, namely, one year life of the spacecraft and its sensors and the generation of images from measurements over about 6.5 million square kilometers daily.

With the exception of three days during early August 1972, the ERTS-1 system has operated and acquired images on every single day since activation on 25 July 1972. During the first six months of operation, nearly 34,000 scenes have been imaged throughout the entire world in each of the four spectral bands. A "scene" is an area 185 kilometers wide and 185 kilometers along the orbital path. This, on the average, amounts to 188 scenes per day.

The three Return Beam Vidicon Cameras and one of the tape recorders needed for acquiring images outside North America were deactivated shortly after launch because of two unrelated electrical malfunctions. However, the Multi-Spectral Scanner and the other tape recorder have functioned normally until 29 March 1973. On that day, the second tape recorder malfunctioned and image coverage of the world outside North America had to be reduced to about 50 scenes or 9000 km long strips per day, since then. However, coverage of North America was not affected.

Most of the major land masses and coastal regions of the world, and both polar caps have been mapped with the ERTS-1 system. Many of the investigators test sites have been mapped periodically and most of North America has been mapped sixteen times since launch, as of mid-May 1973, cloud cover permitting.

RESULTS FROM ERTS-1

Many characteristic features related to earth resources and environmental processes appear distinctly and separately in each of the four spectral bands of the ERTS-1 sensors. The most useful identifications and interpretations can be derived from the contrasts between the visible and infrared portions of the spectrum. This is illustrated in Figures 2a and b which display south-eastern England, with the city of London in the Center, observed on 8 March 1973 in the red/yellow (2a) and the 1.0 micrometer infrared (2b) bands. The two spectral images which were taken simultaneously and are nearly in complete registry, show the drastically different characteristics of most features in the two spectral bands. A portion of the Channel, off the coast of Hastings, which appears relatively dark in both spectral bands, is seen in the lower right corner. The mouth of the Thames, however, shown in the center right, appears relatively bright in the yellow/red band, but very dark in the infrared. This is because in the infrared, any water, regardless of depth, composition or turbidity has extremely low reflectivity, while in the visible, shallow and turbid water is much brighter than clear and deep water. Thus, the very bright areas in Figure 2a, north of the mouth of the Thames (center right) are shallow tidal mud flats; the portion of these mud flats which is exposed and above water can be clearly delineated in the infrared picture (Figure 2b) which is indicated by the about 5 km wide, somewhat brighter strip off the coastline near Southend on the Sea.

The deeper channels cut by the Thames and the tides, as well as the patterns of sedimentation and river effluents can be traced in the yellow/red band (Figure 2a).

Cultural features also appear as nearly opposite brightness patterns in the two bands. For example, the densely built up area of the city of London and the radially spreading transportation arteries show very low brightness in the infrared while in the yellow/red band these areas are relatively bright. Also, the air pollution over the inner city and along the shore of the Thames, east of London, can be clearly identified by the white streaks, streaming off in a southeasterly direction in the yellow/red image (Figure 2a). For reasons which are not fully known at this time but probably related to the composition of the plumes, these air pollution patterns are not apparent in the infrared image (Figure 2b).

Both, dry barren land and vigorous vegetation have a very high reflectance in the infrared. This is seen by the very light areas in the western and southern (left and lower) portions of Figure 2a. A distinction between dry, barren land and vegetation can be made by comparing the infrared picture with the yellow/red one; in the latter, dry, barren land appears bright, as seen in the lower left corner of Figure 2a, while vegetation is generally dark as seen in much of the rest of Figure 2a.

Unvegetated moist ground, especially when covered with deciduous forests whose leaves have fallen, appear very dark in both the infrared and visible bands; the general terrain shown in the upper right quadrant and at the very top of Figures 2a and b belongs in this category.

These differing contrasts in each of the spectral bands can be displayed simultaneously in "false color" composites shown in Figure 2c where the separate ERTS images in the green, red and infrared bands are superimposed on color film. In this particular composite, as well as in most ERTS color pictures, the infrared image was exposed to the red (magenta) dye of the film, the red image to the green dye and the green image to the blue (cyan) dye.

Perhaps the most significant result of the ERTS-1 mission is the realization that features related to land resources or to environmental processes can be mapped synoptically for very large areas on scales up to 1:250,000 without substantial loss of definition. This is illustrated in Figure 3 where two ERTS views of the Alps showing the Inn Valley and Lake Constance were overlayed on a 1:1,000,000 scale map. The ERTS pictures produced from the transmitted signals are displayed on that scale and distortions are minimized so that these pictures serve practically as an instant map whose information content, economy and speed of production far exceed that of a conventionally produced map. These pictures are only "system" corrected, i.e., they are geographically referenced according to the known orbital position of the satellite at the time of observation and to the pointing of the sensor axis which depends on the known spacecraft attitude. No corrections are made for distortions due to non-linearities of the scanner. Yet, such system corrected pictures usually have no greater distortions than several hundred meters over the 185 km scene. These distortions can be further reduced to less than 100 meters by photo-processing on the ground but some of the thematic information content of such "scene corrected" images is sacrificed in the "precision" processing. Objects can be identified in the ERTS-1 pictures and put in the context of their overall environment even on a scale as large as 1:30,000. Such objects include agricultural fields, snow and ice cover, rivers and lakes, tectonic structures, land slides, patterns of civil construction and of urban development. The color composite images of California shown in Figures 4 and 5 are excellent examples for such mapping.

Delineating both the spectral characteristics and spatial or geometric patterns of features observed in ERTS-1 images permits a unique and extremely efficient classification of these features. In a typical agricultural scene such as shown for the Central California Valley (upper right, Figure 4) or for the upper San Joaquin Valley (upper left, Figure 5), 10-20 different categories of land use can be readily and automatically identified. When combined with existing knowledge of a particular area and with sporadic but strategically placed direct observations on the surface, such categorizations have resulted in the accurate identification of crops, measurement of acreages, and in the assessment of stresses on or damages to soils, crops, forests, rangelands or habitats by fires, insect infestations, human interaction, droughts, floods or topographic conditions. Many of these applications were summarized by Poulton (1973).

For example, based on the first ERTS-1 image of the agricultural area of San Joaquin county during July 1972, Colwell et. al (1973) have been able to identify 17 land use and crop types in an analysis which required several orders of magnitude less effort than had this analysis been made by conventional means. That same area is shown eight months later in Figure 4 (upper right). As expected, the agricultural patterns have changed drastically in that period. The very dark area in the upper right, at the eastern end of the San Francisco Bay estuary, had been identified in July as "asparagus, corn and alfalfa field crops" (Colwell, 1973). Now (Figure 4), these fields have no vegetation and are very moist. On the other hand, the large round area in the upper center of Figure 4, just north of the estuary and northwest of the dark region, is characterized by high infrared reflectance, indicating vigorous crops. In the July image that area had been identified as a mixture of fallow and burnt stubble fields. Clear delineations can be made in Figure 4 between the moist, probably freshly plowed, uncultivated fields (very dark grey, regular field patterns), different types of crops (shades of red in regular field patterns) rangeland (light red, irregular patterns) redwood forests of differing density (dark red, irregular patterms) and mountain ranges covered with leafless trees (dark grey, irregular patterns). Some of these features can also be identified in Figure 5 of the Los Angeles area. In dadition, that area exhibits the various alluvial materials covering the Mojave Desert and the striking patterns of urbanization which extends over an 80 x 50 km area in the lower right. The built up center of the city appears bluish grey while the vegetation interspersed with residential areas makes such areas appear pink/grey. Similar patterns of urban development can be seen in Figure 4 in the belt of cities surrounding the lower San Francisco Bay, ranging counter clockwise from San Francisco to San Jose to Oakland.

The very low reflectivity of water in the infrared is used extensively to map the amount of water covering large areas. This is especially significant to assess the damages caused by floods (Figure 6), to plan and direct reclamation operations and to measure the amounts of water available in lakes, reservoirs, or other bodies of inland waters. The yellow/red band is used mainly to distinguish waters of differing quality, to map sedimentation and possibly to recognize biologically productive areas in ocean waters. This has resulted in the detection of natural or manmade processes affecting the quality of water, the quality of wetland areas, and the deterioration of coastlines. Such detection could form the basis of possible action which is required to conserve these resources. The green band is used primarily to analyze water depth because of the transparency of water in this spectral band. Navigational hazards, coral reefs and changes in underwater morphology can be detected and mapped in this fashion.

In the color composite of San Francisco, for example (Figure 4), sedimentation and tidal flow patterns can be mapped in the San Francisco Bay and the outflow from the Bay through the Golden Gate and from various rivers in the Pacific Ocean can be detected.

The assessment and possible prediction of water run-off affecting very large regions can be made by analyzing intricate watersheds such as are displayed in Figure 7 (right) for the entire Western Alps. Water run-off can be computed also from mapping the seasonal variation of snow cover displayed in sequential ERTS-1 images. Such applications have been described by Salomonson (1973). Figure 7 also displays a significant difference in the spectral property of snow between the yellow/red (left) and infrared (right) bands. In the left picture the snow cover stands out by its much higher brightness compared to the surrounding dark terrain. In the right picture it is very difficult to delineate the snow cover, not only because the terrain has a greater reflectivity in the infrared, but also because snow is much darker in that spectral band. Furthermore, melting or old snow such as is seen mostly in this picture of the Alps, is much darker in the infrared than fresh, dry snow. This spectral characteristic of snow is used to map not only snow cover but also the state of snow melting.

The montage of ERTS-1 pictures of the Alps shown in Figure 7 displays very clearly the relationship between river valleys and the tectonic structure. Note, for example, the virtual continuity of the line which extends from the lower Isere and upper Arly valleys (lower left), to the upper Rhone, just east of Lake Geneva (center), to the upper Rhine, south of Lake Constance and finally the Inn slicing through the northern edge of the Alps (upper right). A portion of this feature can be seen in greater detail in Figure 3. Of course, many of these major features relating to geological structure have been mapped before especially in such well explored regions as the Alps. But some, can be put into much better perspective using ERTS-1 images, even where previous explorations have been extensive. An example, of this is shown in Figure 5 where the well known and quite active San Andreas fault can be seen extending from left to right in the center of the picture. Another fault stretches for about 150 km from the center to the lower left toward the coastline at the left edge of the picture. It has been hypothesized (Pease and Johnson 1973) that this fault continues northeastward through the desert along the line marked by the boundary between the blue/green and yellow/white tones in the upper right. Pease and Johnson (1973) have related these previously unknown alignments to recent earthquake activities in southern California. Gawad (1973) has also documented such relationships for other parts of the southwestern U.S. Geological interpretations of ERTS-1 pictures have also resulted in a rather fundamental revision of existing geological maps of Alaska which provide new insight in the potential mineral and petroleum deposits in that State (Lathram et al. 1973). They have also provided for an assessment of nickel and other mineral deposits in South Africa (Viljoen 1973). Many other similar applications were discussed by Lattman (1973).

Generally, 25 to 50 percent new and previously unmapped geological structures are found in ERTS pictures even for relatively well explored areas. In lesser explored areas the new information content of ERTS pictures is even greater: for example, in the Wind River Mountain Range of Wyoming it took about 5 years to map 10-15% of the structural features known today. The remaining 85-90% were mapped from one ERTS picture in 3 hours (Short 1973).

Thus, lineaments expressed as depressions in the terrain or as color tone changes observed in barren regions have been shown to have a significant relationship to mineral deposits, findings of underground water and to the recognition of hazards to major civil construction projects. The derivation of these applications from the ERTS-1 observations is always based on a better understanding of the processes that are shaping the surface of the earth, gained from these observations.

Because of the vertical view of the earth afforded by ERTS and because of the relatively constant scene illumination, ERTS images can be composited and mosaiced easily, thus providing nearly instantaneous, synoptic views of entire states or countries. An example of this is shown in Figure 8 where images obtained from three passes of ERTS-1 over the eastern United States, on 10, 11 and 12 October 1972, were montaged to form one contiguous, synoptic image of the whole area about 500 km wide and 500 km long.

This montage was made from 12 individual ERTS-1 images and was assembled with very little effort. It would have taken almost 50,000 conventional aircraft photos and many man-years of labor to assemble a similar picture from aerial surveys.

The image is dominated by the water bodies of the Chesapeake and Delaware Bays and by their associated estuaries. The white sand covered barrier islands off the Atlantic coast and the marshes and tidelands between them and the mainland are synoptically surveyed. The interface between the silt laden waters of the James (lower left) and Potomac (center left) Rivers and the clearer waters of the Chesapeake Bay are delineated. The geological formations of the Appalachian mountain ridges can be seen in the upper left with the Delaware and Susquehanna Rivers breaking through gaps in these ridges. Land use patterns for this area in which more than 10 percent of the population of North America lives, are evidenced by varying shades of color. Dense forests are shown as dark red, agriculture and range lands are lighter red depending on moisture and crop type, fallow fields and construction sites are very light and swamplands are dark, as are densely urbanized areas; the cities of New York and Philadelphia can be seen in the upper right. Because the evidence of significant geophysical processes and formations is so clearly apparent, these images are also very valuable as an educational tool.

It should be kept in mind that the ERTS-1 system has never been intended to provide such applications on a routine and operational basis. Instead, the primary objective of ERTS-1 was to obtain multispectral images periodically over the United States, and to apply these images experimentally to investigations dealing with various parameters related to earth resources. The fact that after six months of operation of ERTS-1, the use of these observations for purposes such as mentioned above has been taken for granted in many parts of the world, is indicative of the phenomenal success of this first space mission dedicated to nationwide surveys of earth resources and intended to benefit all mankind.

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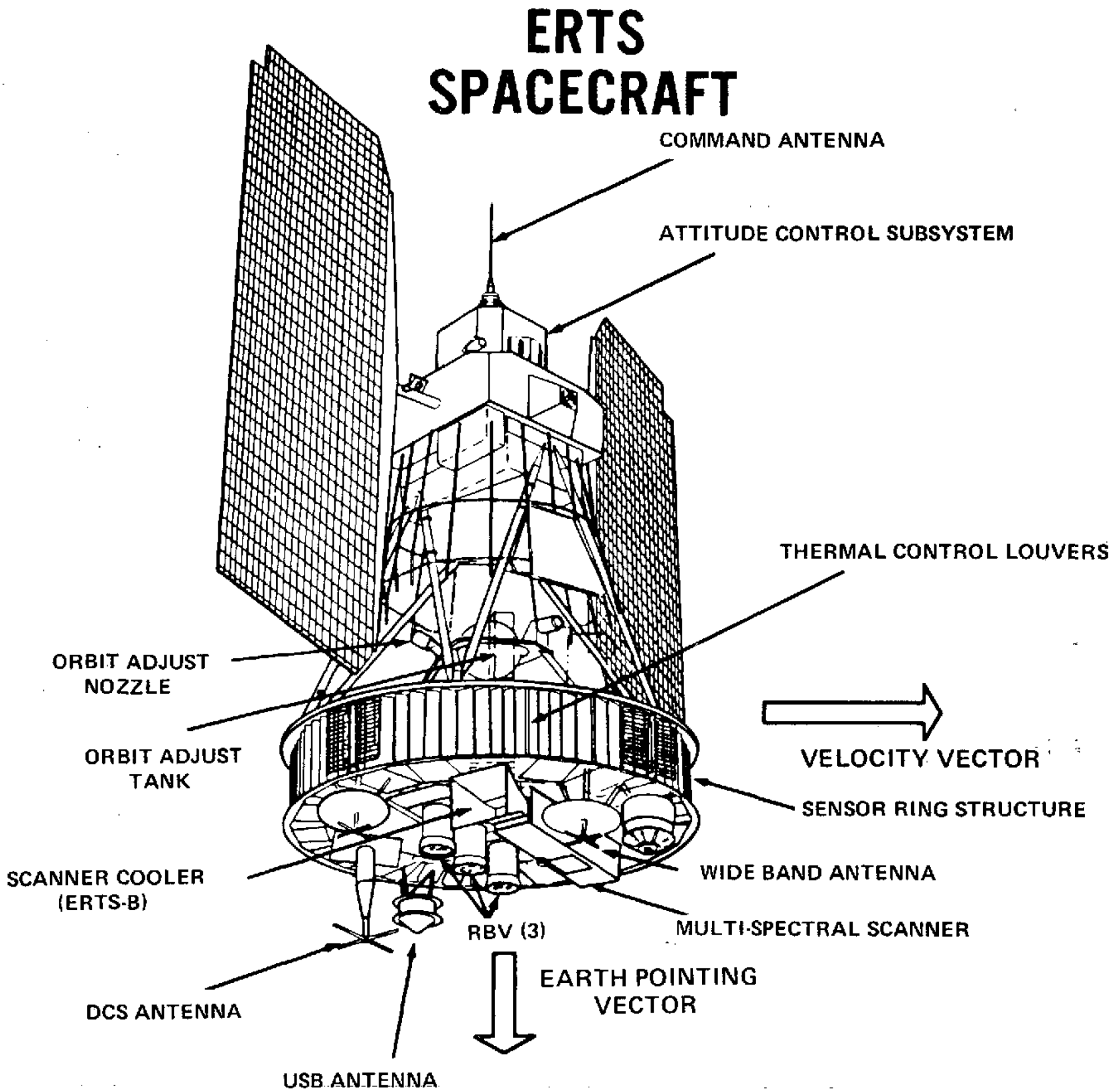
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SPACECRAFT
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ATTITUDE CONTROL SUBSYSTEM
THERMAL CONTROL LOUVERS
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NOZZLE
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TANK
VELOCITY VECTOR
SENSOR RING STRUCTURE
SCANNER COOLER
(ERTS-B)
WIDE BAND ANTENNA
RBV (3)
MULTI-SPECTRAL SCANNER
EARTH POINTING
VECTOR
DCS ANTENNA
USB ANTENNA

Figure 1

Figure 2a

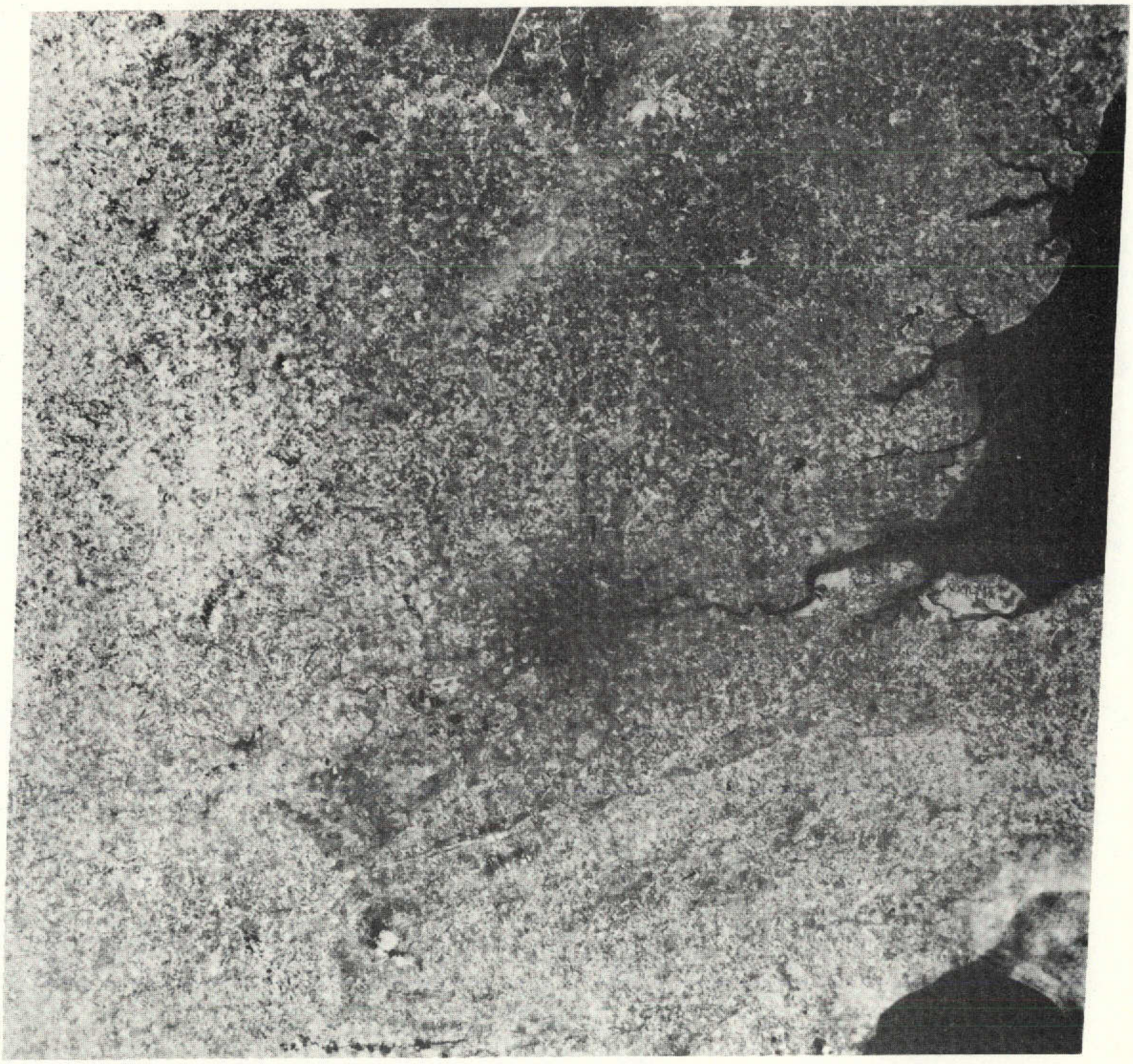

Figure 2b